3

Processing plants and equipment

The process of yoghurt production has evolved through the ages from a simple preparation carried out in the home on a very small scale to medium and large-scale production centres handling many thousands of litres per day. The utensils and equipment required vary in relation to the type of yoghurt produced, scale of production and the level of technology adopted. Hence, it would seem logical to review the available equipment and plant against a scale of yoghurt produced per day:

- Home or small-scale production.
- Medium-scale manufacture by a small producer/retailer.
- Large-scale production.

3.1 Home or small-scale production

Traditionally, yoghurt is prepared at home, and ordinary kitchen utensils are used. The milk is heated in a cooking pot and the production of the coagulum takes place in the same container; Fig. 2.1 showed the overall process in brief. However, one factor that is critical during the incubation period is the maintenance of a uniform temperature. This is achieved by wrapping the pot in a woollen blanket and placing it in a warm place, for example near a cooker. Although the traditional process could still be recommended to individuals producing their own yoghurt, a simplified recipe is illustrated in Fig. 3.1.

The 'airing' cupboard (i.e. area beside the hot water cylinder in a modern house) is sometimes used during the fermentation period, although yoghurt 'makers' (Fig. 3.2) have become available for enthusiasts to produce yoghurt under controlled conditions (see also Taylor, 1981; Davide, 1988; Light, 1993; Hyman *et al.*, 1996). Alternatively, warm milk inoculated with the starter culture (or natural yoghurt) is placed in a wide-mouth vacuum flask and left undisturbed, allowing the milk to ferment and coagulate. Cooling is carried out directly after coagulation has taken place and fruit and/or sugar are normally added to the cold yoghurt.

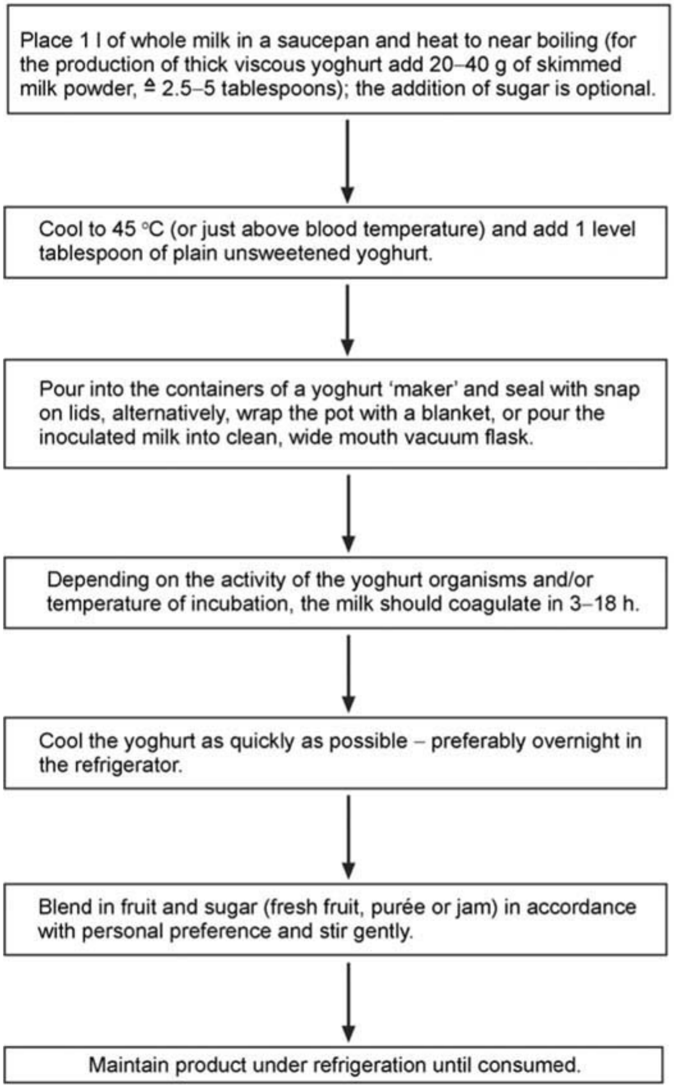

Fig. 3.1 Production of yoghurt at home.

Note the following: (a) one pot of the natural yoghurt produced could be used as a starter culture to inoculate the following batch, (b) excessive subculturing can lead to a prolonged incubation period, and hence it is recommended that a fresh yoghurt should be introduced weekly, and (c) short incubation periods are obtained using fresh, active starter cultures, an approach which is highly recommended.

3.1.1 Miscellaneous systems

The processing steps involved, including the equipment required, in the manufacture of set or stirred yoghurt by this simple procedure are summarised here:

- Milk base is prepared in cans/churns.
- The cans are immersed in a water bath which is required for the heat treatment of the milk; the heat source could be steam or electrical. At the cooling stage, the hot water is replaced by cold water from the mains.

Fig. 3.2 Yoghurt maker where glass jars with screw-on plastic caps are used.

- At 45 °C milk is inoculated with starter culture and incubated in bulk (stirred yoghurt), or for set yoghurt the milk is dispensed into cups prior to incubation; special cabinets can be used for the fermentation, or alternatively the temperature in the water bath can be maintained at 42–45 °C to ferment the milk in bulk.

Fig. 3.3 Hand filling of yoghurt cups.

- At the desired acidity the cans/churns are removed from the incubator unit(s) and stored overnight in the cold store.
- Fruit is added separately to each can/churn and mixed gently using a milk/cream plunger.
- Filling and packaging is carried out using hand-operated units (see below).

3.1.2 Packaging system

For this scale of yoghurt production, it is inappropriate to install a proper packaging machine owing to the high capital investment required. Subsequently, the yoghurt is packaged using hand-operated unit(s), but extreme care should be exercised in order to minimise contamination of the product. Figure 3.3A shows how yoghurt can be produced in a 10 litre stainless steel churn, followed by the addition of fruit on top of the cold yoghurt and mixing. The fruit-flavoured yoghurt is dispensed into plastic cups manually using a stainless steel jug, and finally the aluminium foil lids are crimped in place (Fig. 3.3B–E). Incidentally, an improved method of closure of the yoghurt cups uses a hand-operated heat sealer.

An alternative method of packaging very small volumes of yoghurt per day involves use of a small-scale cup filler. A typical example is the CD 500/1000 machine (see Fig. 3.4). This unit is capable of filling yoghurt cold or hot, and the filling head is fitted with an antifoam nozzle. The capacity of filling ranges between 85 and 600 ml or g, and the piston used for filling the yoghurt has an easy measure adjustment with a fine setting.

(A) (B)

Fig. 3.4 Small filling machine (A) and a thermostatically controlled heat sealer for aluminium foil lids (B).

Reproduced by courtesy of CKX Engineering, Sudbury, UK.

The sequence of operations could be described as follows: place the yoghurt cup on the tray and press the foot pedal; the machine will dose out the set measure of product. The filling head automatically resets when the cup filling sequence is complete and the filled cups are then heat sealed using a separate unit (Fig. 3.4B). The speed of filling depends on the cup capacity and the speed of the operator but, in general, the cup filling speed ranges between 10 and 20 containers min^{1}.

Alternatively, paperboard cartons could be used for the packaging of yoghurt using a hand-operated cartoning and filling machine (Fig. 3.5). This method of filling yoghurt could be referred to as a hand form-fill-seal operation. The hand-operated bottom carton sealer (Fig. 3.5A) preforms, crimps, heats, folds and bottom seals all sizes of carton, and pre-breaks the tops in preparation for the 'top sealer'; incidentally, a similar unit was illustrated in the first edition of this book and the design has been changed to include an air-operated base sealing plate.

The hand filler/sealer is basically designed for liquid milk but, by slightly modifying the filling head, it becomes feasible to fill a viscous product such as yoghurt (see Fig. 3.5B). The preformed cartons are placed under the filler and a microswitch operates the fill time. Then, the carton is pushed under the sealer and the handle is pulled to seal it. The speed of both the hand carton/sealer and the filling/sealing machine is about 10 units min^{1}.

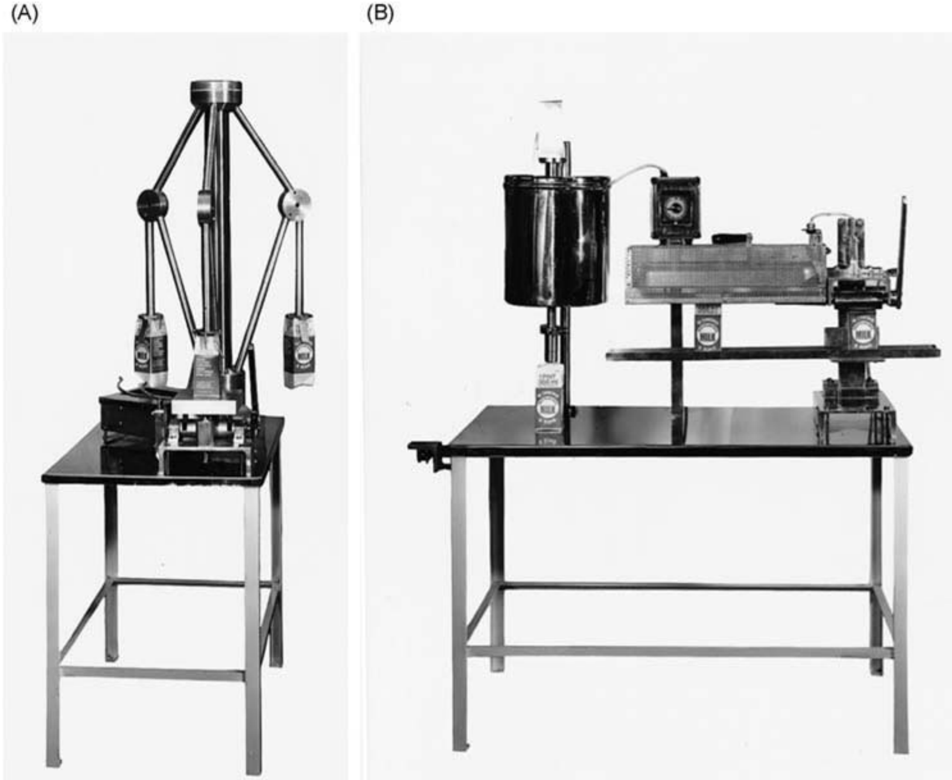

Fig. 3.5 Hand-operated packaging equipment for filling yoghurt into cartons. (A), Carton maker/sealer, (B), hand filler sealer.

Reproduced by courtesy of CKX Engineering, Sudbury, UK.

3.2 Medium-scale production

The volume of yoghurt production in this category is rather low, perhaps in the region of a few hundred litres per day, and such small producers/retailers aim to market their yoghurt within a limited area (see also Muller and Weijenberg, 1991). The different types of equipment that could be used at this level are described below (see also IDF, 2001).

3.2.1 Hand-operated vat

In some parts of the world, equipment manufacturers may produce specially designed small processing vessels (i.e. hand-operated, multi-purpose tanks) where the agitation of the milk base during heating and cooling is done manually. The different steps involved during the production of yoghurt can be summarised as follows:

- Sanitise the equipment directly using chemical sterilising agents, drain and rinse with clean water.
- Pour the milk into the vat, add the required amount of dried ingredients (milk powder) and mix with the aid of a stainless steel wire whisk.
- Start the heating cycle using an electric element to heat the insulated water jacket and hand agitate the milk.
- After reaching the desired temperature, the heating element is switched off and the milk is held for 10–30 min (depending on temperature), prior to cooling.
- During cooling, the water in the jacket is replaced by circulating mains water. At 40–45 °C the milk is inoculated with starter culture and left undisturbed during the fermentation period.
- After a few hours, or at the desired acidity, mains water is circulated through the jacket to cool the coagulum, a process that may be assisted by gentle agitation.
- At around 15–20 °C, a known volume of yoghurt is drained out, mixed with fruit/flavouring additives and hand-filled into plastic cups.

3.2.2 Multi-purpose vat

This type of vat is really a batch pasteuriser which is slightly modified to meet the requirements of yoghurt manufacture. It is widely used for the production of viscous yoghurt (Fig. 3.6). These vats are usually made of stainless steel and insulated with a water jacket. The capacity may be in the region of 50–2250 l. When this type of vat is used, the processing stages of stirred yoghurt production usually follow two alternative patterns. In the first approach the vat is utilised for all the different steps necessary for the preparation and production of yoghurt (Fig. 3.7, process A). However, in the second approach the vat is merely used for the preparation of milk, that is, mixing the dried ingredients with milk, heat treatment and cooling to incubation temperature (Fig. 3.7, process B).

Processes A and B described in Fig. 3.7 illustrate clearly the steps necessary to produce stirred yoghurt, but for the manufacture of set yoghurt, process C (Fig. 3.7) should be followed. Processes B and C are similar except that in process B the milk is fermented in bulk, while in process C the milk is incubated in the retail container. The major differences between set and stirred yoghurt are illustrated elsewhere (see Chapters 2 and 5).

The multi-purpose vat (Fig. 3.6) can be heated using different sources of energy (e.g. electrical, steam or gas) and this versatility makes this type of processing equipment very

Fig. 3.6 Typical batch pasteuriser which can be used as a multi-purpose vat for the production of yoghurt. Gusti-steam, electric or gas heated 'Pastomix' – 'Pastolux' vat for heat treatment of the milk base or cold storage of yoghurt (see text).

Reproduced by courtesy of T. Gusti, Wellingborough, UK.

popular with the small producer. During the cooling stages, mains water can be used or a closed-circuit cooling system circulating chilled water may be employed. However, if in-tank cooling is used for cooling the yoghurt, a slow-speed agitator (i.e. <45 rpm) is operated to mix the coagulum gently and assist cooling but, at the same time, inflict minimum reduction in viscosity on the product. The diameter of the outlet valve must be ≥ 5 cm in order to facilitate ease of drainage of the yoghurt. On such a small scale of production, the stages of fruit mixing and filling can be carried out manually, but great care must be taken to minimise post-production contamination. Figure 3.7, process B, illustrates this approach. The fruit is added to each can/churn and gently mixed with the yoghurt by means of a milk/cream plunger.

3.2.3 Mini dairy science and technology

The 'mini dairy' is a small compact processing plant that was developed in the late 1970s by Alfa-Laval A/B, Lund in Sweden – a project sponsored by the Swedish government to establish small-scale milk processing units in the developing countries. At present, Tetra Pak and Alfa-Laval Agri are responsible for marketing of these units in different parts of

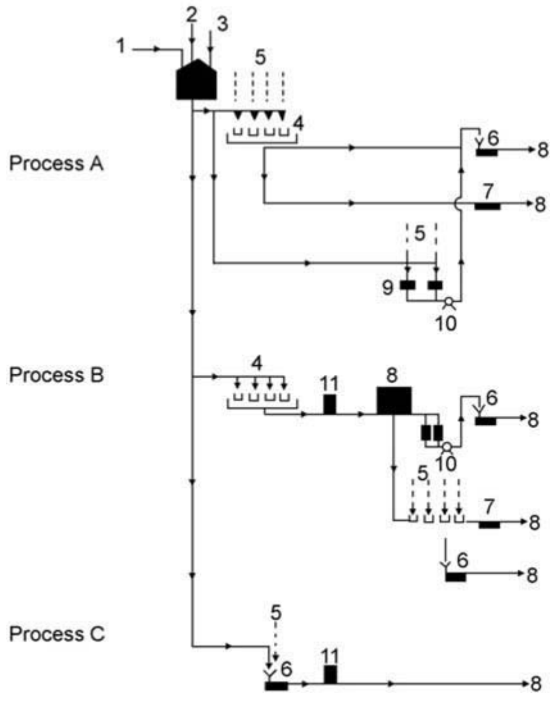

Fig. 3.7 Small-scale production of yoghurt using a multi-purpose tank.

1, Inlet for liquid milk; 2, dried ingredients (milk powder(s) and sugar) added manually; 3, starter culture added manually; 4, stainless steel churns (process A – contain cold yoghurt – or process B – processed milk base inoculated with starter culture); 5, fruit added manually; 6, small-scale filling machine; 7, hand-filling machine; 8, cold store; 9, two small tanks (in parallel) used for the addition of fruit with yoghurt so that filling can be continuous; 10, positive pump; 11, incubation cabinet for set yoghurt (process C).

the world. The mini dairy unit is basically designed for processing market milks, cheese and fermented milks. For yoghurt, for example set, stirred and/or drinking type, the unit is capable of producing 1000 l per batch over an extended 8 h shift. All such units are pre-assembled and tested to give a short and efficient installation and start-up time. The energy required for heating and cooling is provided by mains electricity or a diesel-powered electric generator and hot water is generated by an oil- or wood-fired furnace. Figure 3.8 illustrates a unit for processing milk for the manufacture of the products mentioned above (Gandhi, 1986; Caviezel, 1987; Briem, 1992; Olivetti, 1993; see also Capogna *et al.*, 1997; Gran *et al.*, 2002).

3.2.4 Small-scale packaging machines

Although hand filling has been adopted by many small dairies, the use of a proper filling machine does offer some advantages. A wide range of fillers is available on the market, and these filling machines are equipped with a diversity of sealing mechanisms, for example the ability to heat-seal foil lids, crimp foil lids or snap-on plastic lids. The ultimate selection of a particular type is largely a matter of personal preference (see Platt, 1990; Anon., 1998). Most manufacturers of packaging machines also produce small-scale equipment to meet the demand from small dairies. Some examples follow.

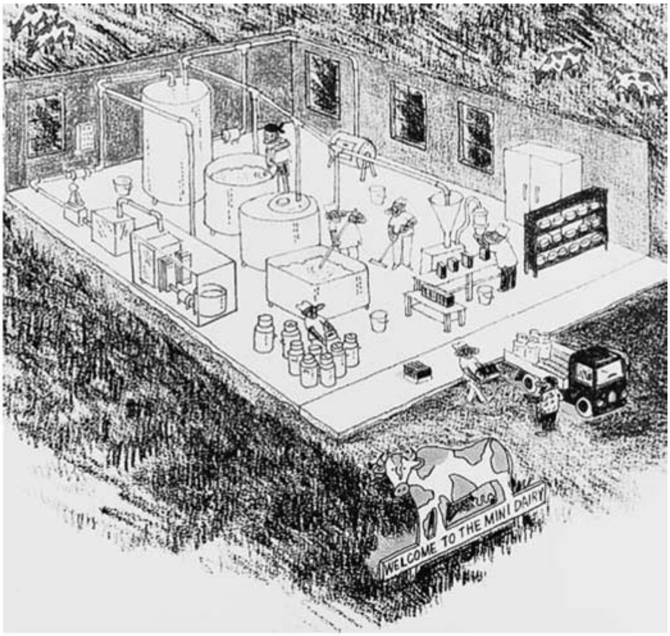

Fig. 3.8 General view of a mini dairy processing plant.
Reproduced by courtesy of Tetra Pak A/B, Lund, Sweden.

Regal RP/SA2
This machine is semi-automatic and consists of:

- stainless steel hoppers that hold the yoghurt and the fruit base;
- stainless steel rotary table;
- a foil dispensing assembly with a spot sealer;
- heat sealing assembly.

An illustration of this machine is shown in Fig. 3.9. The sequence of operation is as follows: (a) the preformed containers are loaded into the machine by hand and a photoelectric cell (PEC) detects their presence, (b) the operator indexes the rotary table clockwise to the filling assemblies, (c) when the container is filled (i.e. with fruit-flavoured yoghurt or, in a two-step sequence, with fruit and the yoghurt base, separately), the operator indexes the rotary table clockwise to the foil dispensing assembly where a foil is placed automatically and spot sealed in position, and (d) the operator then indexes the table to the heater assembly where the aluminium foil lid is heat sealed automatically.

As the operator indexes the rotary table once more, this allows removal of the filled yoghurt containers. However, every time the table is indexed, another container should be loaded to repeat the cycle. The volume of the fruit dispensing unit ranges from 10 to 80 ml, and for yoghurt 60 to 300 ml. Incidentally, the machine is fitted with a fully interlocked stainless steel mesh safety guard. The same manufacturer produces fully automatic filling machines up to 12 000 cups h^{-1}.

Waldner Dosomat 1 Eco, 1, 2 and 10
These are rotary cup filling and closing machines that cover capacities ranging from 1000 to 20 000 cups h^{-1}. These machines are fully automatic with the dosing unit mechanically driven; this unit operates on the piston principle, which ensures filling with absolute care

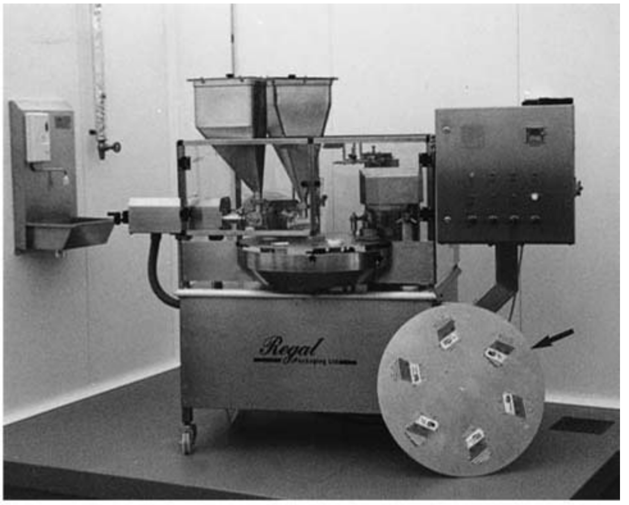

Fig. 3.9 General view of the Regal semi-automatic.

Note: Arrow indicates stainless steel table specially designed for filling twin chamber container.

and accuracy. For viscous products such as yoghurt, product aspiration is realised by direct feed via equalising pistons and the dosing range is regulated by handwheel. A range of containers (e.g. cartons, plastic pots or glass bottles) can be used on this machine for packaging yoghurt. Figure 3.10 illustrates one example operated within a laminar flow cabinet hood. All models of the rotary Dosomat machines are fitted with a coding system of one of the following types:

Fig. 3.10 Waldner Dosomat rotary-type yoghurt filling machine.

Reproduced by courtesy of Ultrapak, Aldershot, UK.

- coding with quick drying ink or hot stamping with ink ribbon on the lid or cup bottom;
- heat or cold embossing into cup bottom;
- labelling;
- ink-jet.

The closure of the container (i.e. heat sealing with a snap-on lid) can be achieved by heat, ultrasonic or high-frequency sealing. All models are suitable for clean-in-place (CIP). Incidentally, the number of filling lanes on the rotary table ranges from one up to eight, depending on the model and throughput.

GEI Turbo Rotafil
This is a multifunctional compact system of filling. The machine is available with different sizes of interchangeable indexing table for packaging into a wide range of container sizes. It can be supplied with many optional features such as:

- automatic container dispenser and discharge systems;
- multi-station or filling head facilities;
- automatic closure, heat sealing and securing of anti-tampering devices;
- date and price coding system.

The filling speed is around 8400 pots h^{-1} on a four-head production system. However, the specially designed filling head (see Fig. 3.11) ensures that there is a regulated speed of filling, capacity to deliver fruit pieces intact into fruit-flavoured yoghurt, and virtually drip-free cut-off between the fills.

Fig. 3.11 Filling heads on Turbo Rotafil packaging machine.
Reproduced by courtesy of GEI International, Woburn Sands, UK.

Cockx R 4000

The machine is a 16 pocket, eight station unit with options of pre-fill and over-lid (Fig. 3.12). In general, it is fitted with cup magazines, mechanical main piston fill, lid appliers, heat sealers, date coders and cup ejection onto a conveyor with an extended collection table; the filling speed is about 4000 cups h^{-1}.

The machine has been designed to allow, if required, two different products to be filled at the same time as the starwheel indexes two pockets at a time. The filling valves are independent and, as an extra, two hoppers can be fitted as an alternative to the single unit. If the pre-fill extra is used, then larger capacity cups can be filled faster with a pre-dose prior to the main fill. The nozzles can be changed for different products and have a positive cut-off. The measure adjustment is inside the main frame of the machine, easily accessible through the interlocked doors. The lid magazines can be switched independently and can be changed for containers of different rim size. The heat seal heads have easily changeable seal plates and the date coders can be quickly adjusted for height and position. The filled and sealed cups are raised out of the pockets and swept onto a deadplate prior to being pushed onto a small conveyor, where they are guided onto a collection table for packing.

The fill, lid application and heat-seal systems are all controlled by sensors and all doors are fully interlocked for safety. There are no process controllers fitted to the machine and the mechanical variable speed drive is connected to the piston fill drive system by a chain and is also connected to a camshaft. This camshaft has a series of roller-operated valves operated by individual cams which are easy to set up or adjust. In this way, it is easy for the customer to understand the working of the machine at each station. Lubrication ports are on one panel with the feeds through copper tubes to the bearings.

Fig. 3.12 Cockx rotary cup filler and sealer.
Reproduced by courtesy of CKX Engineering, Sudbury, UK.

3.3 Large-scale production

In this category, the equipment employed for the manufacture of yoghurt is specially designed to handle thousands of litres per day and a highly sophisticated technology has evolved which offers a dairy both improved mechanisation and automation. Since the publication of the first edition of this book, few technical developments have occurred with respect to yoghurt technology and the latest technological progress in this field has been reviewed in two International Dairy Federation monographs (IDF, 1988, 1992). Driessen and Loones (1992) presented a comprehensive chart summarising the new developments in technology including products with special microorganisms as follows:

- Membrane techniques which make it possible to utilise the required properties and avoid the unwanted properties of microbial metabolites.
- Separate cultivation which makes it possible to combine microorganisms that need differing conditions for their proliferation, for example, mesophilic and thermophilic strains.
- Applying automatic pH control to end the fermentation process and achieve a more consistent product.
- Mounting the cooler on top of the filler, to achieve better viscosity in stirred fermented milks.
- Applying in-line inoculation which makes manufacture of set fermented milks more flexible.
- Overpressure of sterile air which has proved to be effective in protecting starters against contamination with other micro-organisms and bacteriophages.

The topic has been extensively reviewed elsewhere (Anon., 1981a,b, 1983a; Salji *et al.*, 1985; Evavoll, 1985; Nicolaus, 1987; Bianchi-Salvadori, 1989; Driessen and Loones, 1990, 1992; Nilsson and Hallström, 1990; Robinson and Tamime, 1990, 1993; Puhan *et al.*, 1994a,b; Nilsson, 1994; Strahm and Eberhard, 1994; Karagozlu and Gonc, 1996; Gardini *et al.*, 1996; IDF, 1998, 2003; Tamime *et al.*, 2001; Storro, 2002; Anon., 2003; Tamime, 2006). As a consequence, it was decided that only up-to-date information will be provided here.

The diversity of these technologies can be discussed most easily in relation to:

- type of yoghurt produced (e.g. set or stirred);
- effect of mechanisation on the quality of the yoghurt;
- application of automation to the manufacture of yoghurt.

There are several approaches that can be employed for the production of yoghurt and, as each yoghurt manufacturer has their own specific requirements, each plant is supplied, in effect, tailor made. It is evident that plants that produce set and stirred yoghurt (or a combined processing plant) have some stages in common (see Fig. 3.13), for example, milk reception and handling, preparation of the milk base, homogenisation of the yoghurt milk and heat treatment, and hence it is appropriate to review the relevant equipment in relation to the different stages of manufacture; more specialised units are discussed separately.

3.3.1 Milk reception, handling and storage

At present, milk collection from farms in developing and industrialised countries is carried out in bulk using a road tanker although, in some instances, rail tankers or churns could be used. The facilities provided at a typical dairy for reception of this bulk milk

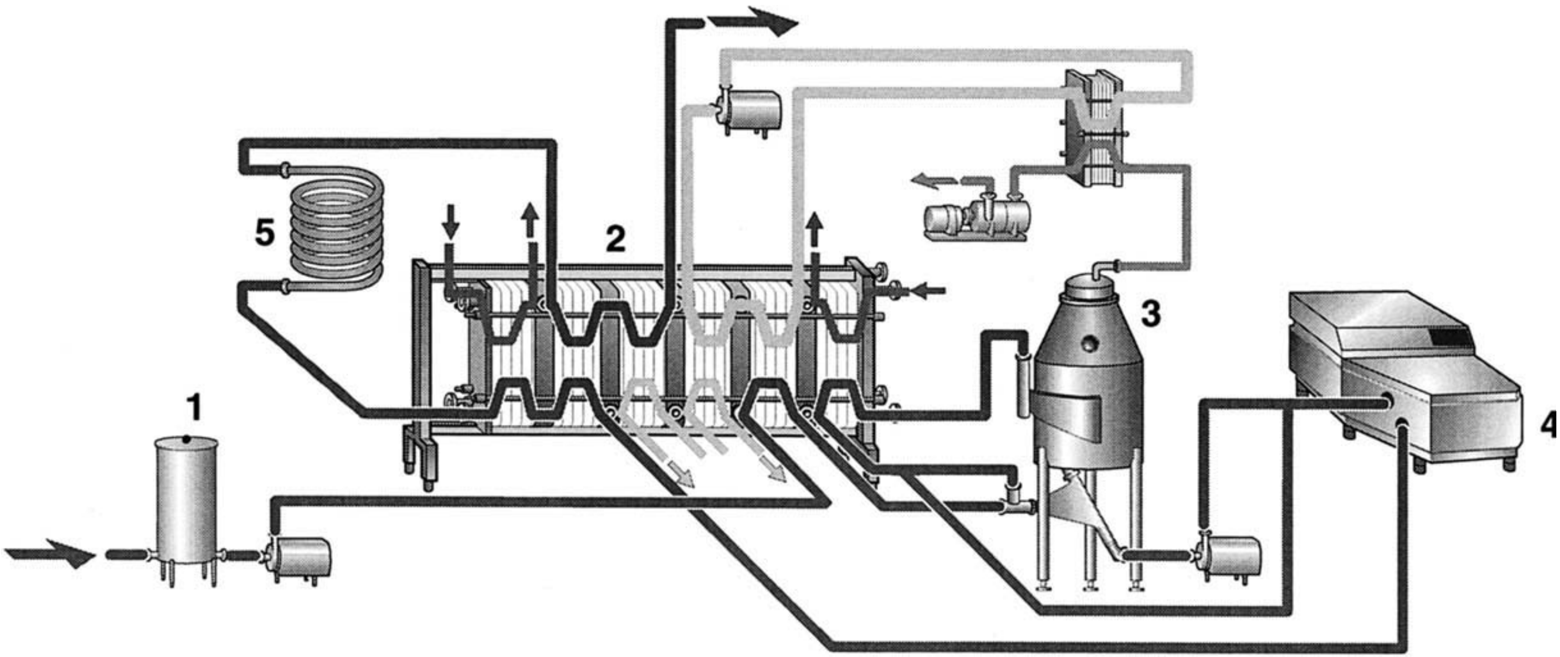

Fig. 3.13 Flow diagram of general pre-treatment of milk for the manufacture of set and stirred yoghurts. 1, Balance tank; 2 plate heat exchanger (PHE); 3, evaporator; 4, homogeniser; 5, holding tube. Reproduced by courtesy of Tetra Pak A/B, Lund, Sweden.

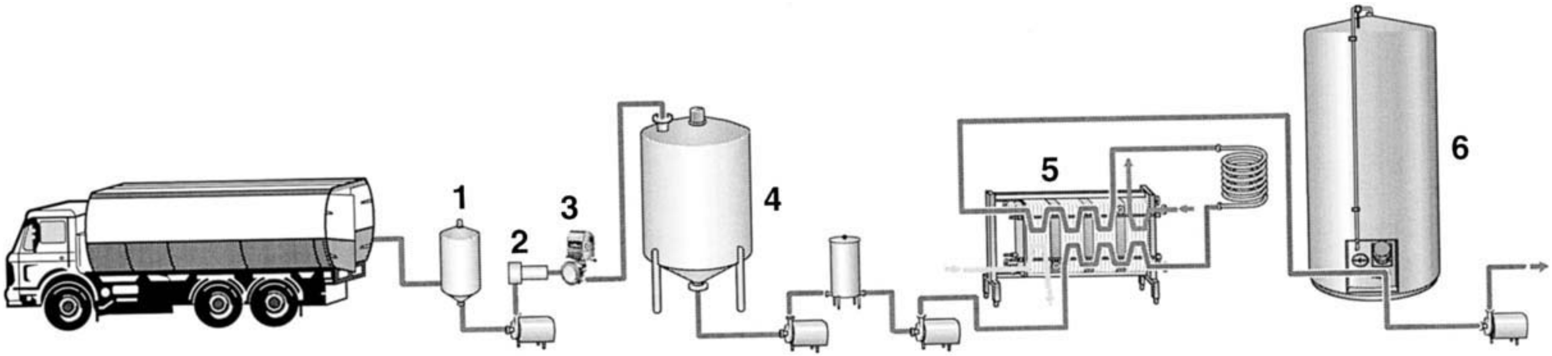

Fig. 3.14 Milk reception, handling and storage at a large factory.

1, Air eliminator; 2, filter; 3, milk meter; 4, intermediate storage tank; 5, thermisation and cooling or cooling only; 6, silo tank.

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have been described by Tamime and Kirkegaard (1991), Anon. (2003) and Tamime *et al.* (2006) (see Fig. 3.14). The milk intake can be either metered using a metering pump, or weighed (e.g. at a weighbridge for road tankers or in a duplex weighbowl for churns). When milk is accepted, and after a sample for chemical and microbiological analysis has been taken, the general practice for handling the milk may include: (a) filtering the milk to remove contaminants (e.g. straw, hairs, soil) with the most universal system used being a stainless steel filter; however, an optional treatment to clean the milk is clarification using a separator; and (b) cooling the milk to <5 °C using a plate cooler prior to storing in a silo.

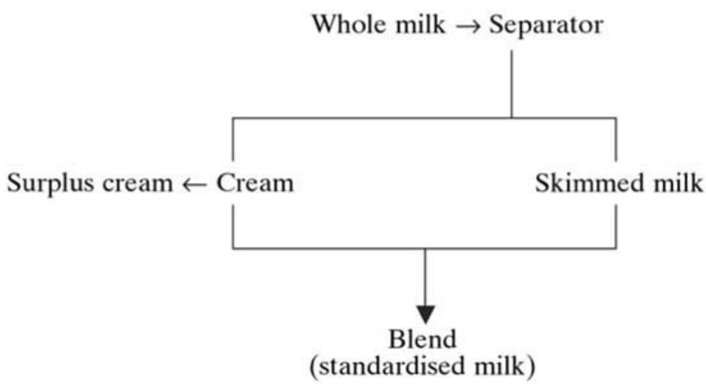
The reception of milk in churns is somewhat different from reception from a road tanker. Normally the churns are unloaded in the reception area and the lids removed. The freshness of the product is quickly determined by sniffing the churns and if any unusual smells are noted, the milk is rejected; a composite sample of milk from each farm is further analysed chemically for bacteriological quality.

As already discussed elsewhere (see Chapter 2), the milk is subjected to a number of preliminary treatments before it becomes yoghurt. These processes are standardisation of the fat content, fortification of the solids-not-fat (SNF) and homogenisation and heat treatment of the milk base. These treatments will be discussed separately.

3.3.2 Standardisation of fat content in milk

The fat content of milk can vary according to source and season, but in yoghurt the level is prescribed by consumer taste or the Statutory Instruments of the countries concerned, so that standardisation becomes essential.

The theoretical approach to milk standardisation can best be visualised as follows:



and the accuracy of the process is dependent on such factors as:

- type of equipment used and the efficiency of fat separation obtained;
- control system used.

The skimming efficiency of the available plant has greatly improved over the years, so that residual fat in skimmed milk usually falls between 0.05 and 0.07 g 100 g^{-1}; the skimming efficiency of the separators is thus referred to as 0.05 or 0.07, respectively. The control system employed in milk standardisation lines can be either manual or automatic, and while the former may be recommended for small/medium size producers, the automatic system is essential for dairies handling large volumes of milk per day.

A number of different systems can be used for milk standardisation (Hellström, 1986; Anon., 1992, 1996a; Bird, 1993). The efficacy of any one particular system depends on its ability to ensure that:

- the pressure of the skimmed milk at the outlet pipe is lower than the pressure in the tank where the skimmed milk and cream are remixed;
- the fat content in the cream remains constant; the proportion of cream remixing with skimmed milk can be stabilised, i.e. there are proportional mixing controls;
- the final fat content of the process milk is within preset limits.

Compomaster KCC

This is an automatic system for standardisation of the fat content in the milk and surplus cream (Fig. 3.15). This unit is directly connected to a separator; however, when liquids are mixed continuously in volumetric proportions, the Compomaster can be used without a separator. In this system of standardisation, combined mass flow meters, density meters and temperature transmitters are used to measure the cream and skimmed milk, respectively (Hansen, 1996). Thus, by knowing the density and temperature of both skimmed milk and cream, it is then possible to calculate the fat content of the cream. The unit automatically adjusts to the set points for the fat content in both standardised skimmed milk (1–5 $g\,100\,g^{-1}$) and cream (18–50 $g\,100\,g^{-1}$).

The Compomaster has capacities ranging between 7000 and 45 000 $l\,h^{-1}$. It is delivered as a compact unit ready for installation and connections need to be made to the product inlet, air-line and the mains electricity supply. According to Hansen (1996), the Compomaster type KCC standardising system needs to be calibrated only once every second year reflecting the high precision of the unit. This system also contains in-line mixers for special applications (i.e. mixing cream and skimmed milk) without the use of a separator; furthermore, this system is suitable for CIP application.

Automatic direct standardisation (ADS) Systems

These methods of standardisation of the milk and cream are very accurate and depend on a careful choice of components and the design and engineering of the system. A typical system is shown in Fig. 3.16, where the components within the system are clearly identified. In brief, according to Bird (1993) and Anon. (2003), the ADS system can be described as follows.

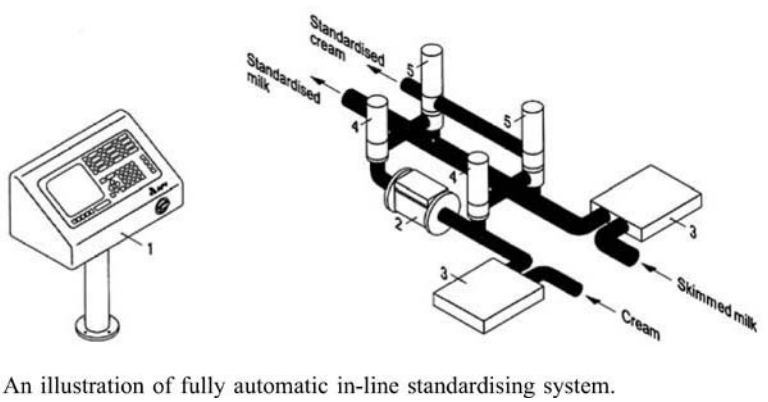


Fig. 3.15 An illustration of fully automatic in-line standardising system.

1, Control panel; 2, flow meter; 3, density transmitters; 4, regulating valves; 5, on/off valves.

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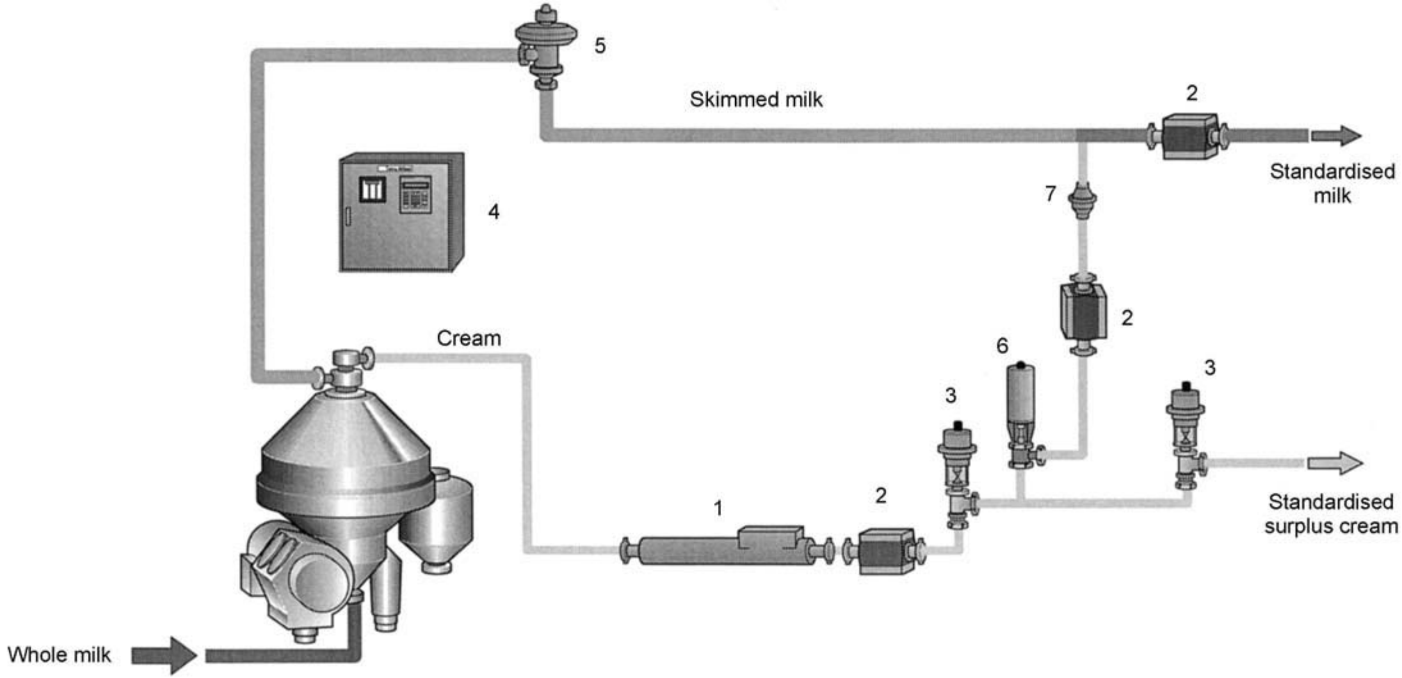

Fig. 3.16 Illustration of an automatic direct standardisation (ADS) system for milk and cream.

1, Density transmitter; 2, flow transmitter; 3, control valve; 4, control panel; 5, constant pressure valve; 6, shut-off valve; 7, check valve.

Reproduced by courtesy of Tetra Pak A/B, Lund, Sweden.

The set points for standardised cream (or surplus cream) and milk fat content are fed into the process control unit. The pressure control system at the skimmed milk outlet (Fig. 3.16 (5), constant pressure valve) maintains a constant pressure, regardless of fluctuations in the pressure drop over downstream equipment. The cream-regulating system maintains a constant fat content in the cream discharged from the separator by adjusting the flow of cream discharged. The ratio controller mixes cream of constant fat content with skimmed milk in the correct proportion to give standardised milk with a specified fat content. The accuracy of the system, based on standard deviation of repeatability, should be <0.03% for milk and about 0.25% for cream (see also Hellström, 1986; Anon., 1992).

The application of these systems to the manufacture of yoghurt could be considered under the following conditions: (a) if the solids content of the milk is fortified using an evaporator (Figs 3.13 and 3.17), then it is necessary to standardise the fat content in the milk before the concentration process commences, (b) skimmed milk could be concentrated by evaporation and then before further treatments (i.e. homogenisation and heat treatment) the concentrated skimmed milk could be standardised with cream, (c) concentrated skimmed milk may be standardised with cream, and (d) membrane filtration (ultrafiltration, UF, or reverse osmosis, RO) is sometimes used to concentrate the milk base. Normally, the fat is separated from whole milk and the skimmed milk is concentrated to the desired level of solids; the concentrated skimmed milk fraction is then standardised with the cream.

In general, therefore, the milk base is standardised for fat content before evaporation commences but, if the skimmed milk is concentrated in a UF plant, the addition of cream takes place later. The reason for adding the fat to the concentrated skimmed milk in the

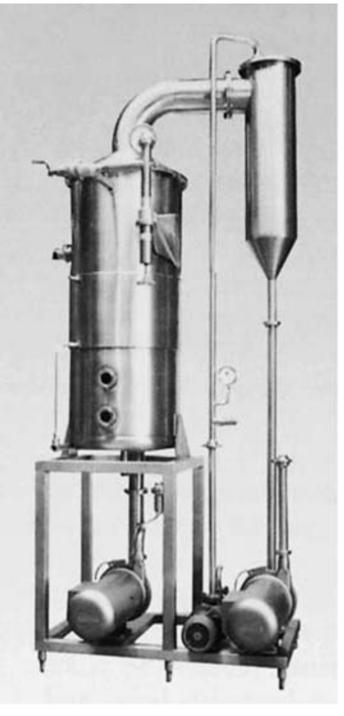

Fig. 3.17 View of an internal evaporation and de-aeration plant used on a yoghurt processing line.

Reproduced by courtesy of APV Nordic, Denmark.

latter method is that the high pressure used during the concentration process could damage some of the physical properties of the fat, which in turn may affect the quality of yoghurt (e.g. an oiling-off or a churning effect). Alternatively, if on-line fortification of the milk base with the use of membrane processing or vacuum evaporation is used, the fat content is standardised before concentrating the milk, taking into account the factor of concentration. For example, to raise the protein content in the milk base from 3.2 to $5\,g\,100\,g^{-1}$, the concentration factor is *c.* $\times 1.56$. Therefore, the fat is standardised to 1 or $2.24\,g\,100\,g^{-1}$ during the manufacture of low- or full-fat yoghurt ~1.5 or $3.5\,g\,100\,g^{-1}$ in the final product, respectively (Tamime *et al.*, 2001; see also Nissen, 1999; Heggum, 1999; Jensen, 1999; Andersen and Johansen, 1999).

OL-7000 system

This is another method for on-line standardisations of the fat content in the milk base. It is manufactured by On-Line Instrumentation Inc. in the United States. This model is the third generation design and ensures that the fat content is within $\pm 0.02\,g$ fat $100\,g^{-1}$ of the target level in the final milk base with 95% confidence. Illustration and operation of OL-7000 system have been reported by Muir and Tamime (2001), and the same system can be used to standardise concentrated milk with cream to the desired fat content (Tamime *et al.*, 2001).

3.3.3 Fortification of milk solids

The level of milk solids in the milk base can be raised by one or more of the following methods.

Traditional process

Boiling the milk can be carried out in a tank similar to a batch pasteuriser. The aim of this approach is the evaporation of one-third of the milk volume under atmospheric pressure. However, this method of concentration of the milk solids is not used under industrial conditions, mainly owing to the high cost involved, but also because the generation of too much steam in the processing area can be unacceptable to personnel.

Addition of milk powder

Different types of milk powder can be used to fortify the yoghurt milk (see Chapter 2), although skimmed milk powder is used most widely. The dried ingredients are incorporated into the aqueous phase which could be whole milk, skimmed milk or water, and the available equipment is designed to provide: (a) complete dispersion of the dried ingredients into the aqueous phase, (b) complete hydration of the dried particles with no residual lumps, (c) minimal incorporation of air in order to reduce the problems of foaming, and (d) easy cleaning and sanitisation of the unit.

The powder-handling equipment found in a dairy is dependent on the daily throughput and the method of bulk delivery. Basically, milk powder is packed into either small capacity units (25–50 kg multilayer paper sacks with polythene liners), medium capacity units (up to a tonne in metal or plastic containers) or road tankers for bulk storage in metal silos. The machinery available for emptying the powder also varies, so that while the sacks (small quantities) may be emptied directly into reconstitution units, larger volumes are emptied into a sifter for delivery into the mixing unit. The powder stored in metal/plastic bins or silos is transferred using either a screw-feed (of variable speed) or a blower; dust filters must be used to recover any fine particles, especially in

plants handling large capacities. Some examples of milk powder mixing units are given below.

Mixing funnel/hopper

Reconstitution of the powder is carried out in batches and a 'closed circuit' consisting of a tank, pipe connection, centrifugal pump and the funnel/hopper assembly is required. The tank is normally filled with the aqueous phase at around 40–50 °C and the circulation started. The positioning of the hopper in relation to the centrifugal pump is important, and two options are available (see Fig. 3.18):

- First, if the hopper is assembled on the suction side of the centrifugal pump, it offers the advantage of rapid dispersal and adequate dissolution of the powder owing to the action of the pump; the disadvantage is that frequent blockages may occur in the hopper.
- Second, by placing the hopper on the outlet side of the centrifugal pump directly after a specially designed venturi unit, the problem of blockage is overcome, since the venturi unit creates a vacuum within the pipe causing the powder to be sucked into the recirculating solution; full dispersal of powder may be a little slower (Newstead *et al.*, 1979; Sanderson, 1982).

The former circuit is illustrated in Fig. 3.19. It is noticeable that, in the latter approach, any suction of air is returned to the tank rather than the suction side of the pump, because if air is introduced into the system, the action of the pump's impeller can increase the amount of air incorporated into the product. Furthermore, a reduction in aeration and/or frothing can be achieved by installing a special valve on the mixing hopper and ensuring that the return line in the mixing tank is below the level of the liquid. If additional mixing of the added powder is required, one of the following units could be employed: (a) in-line static mixer, (b) high-speed agitator in the mixing tank or (c) high-velocity liquid jet.

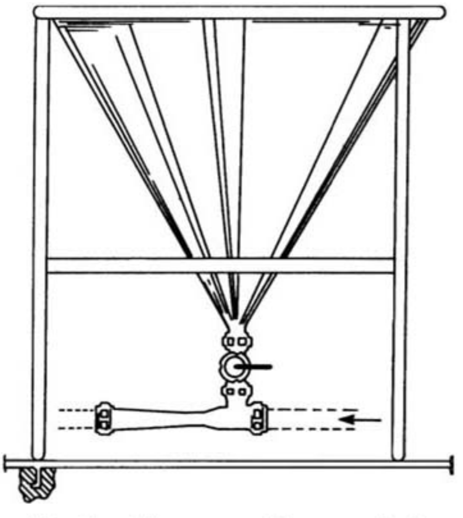

Fig. 3.18 Illustration of a mixing funnel/hopper-used for reconstitution of milk powders.

The sack of milk powder is placed on the table and then emptied into the funnel. The force of the circulating liquid causes the powder to be aspirated downwards and mixed with the water. Circulation is continued until the powder is dissolved. Notice that the funnel has a valve connection, which has a slight constriction/restriction in the pipe to provide a venturi effect.

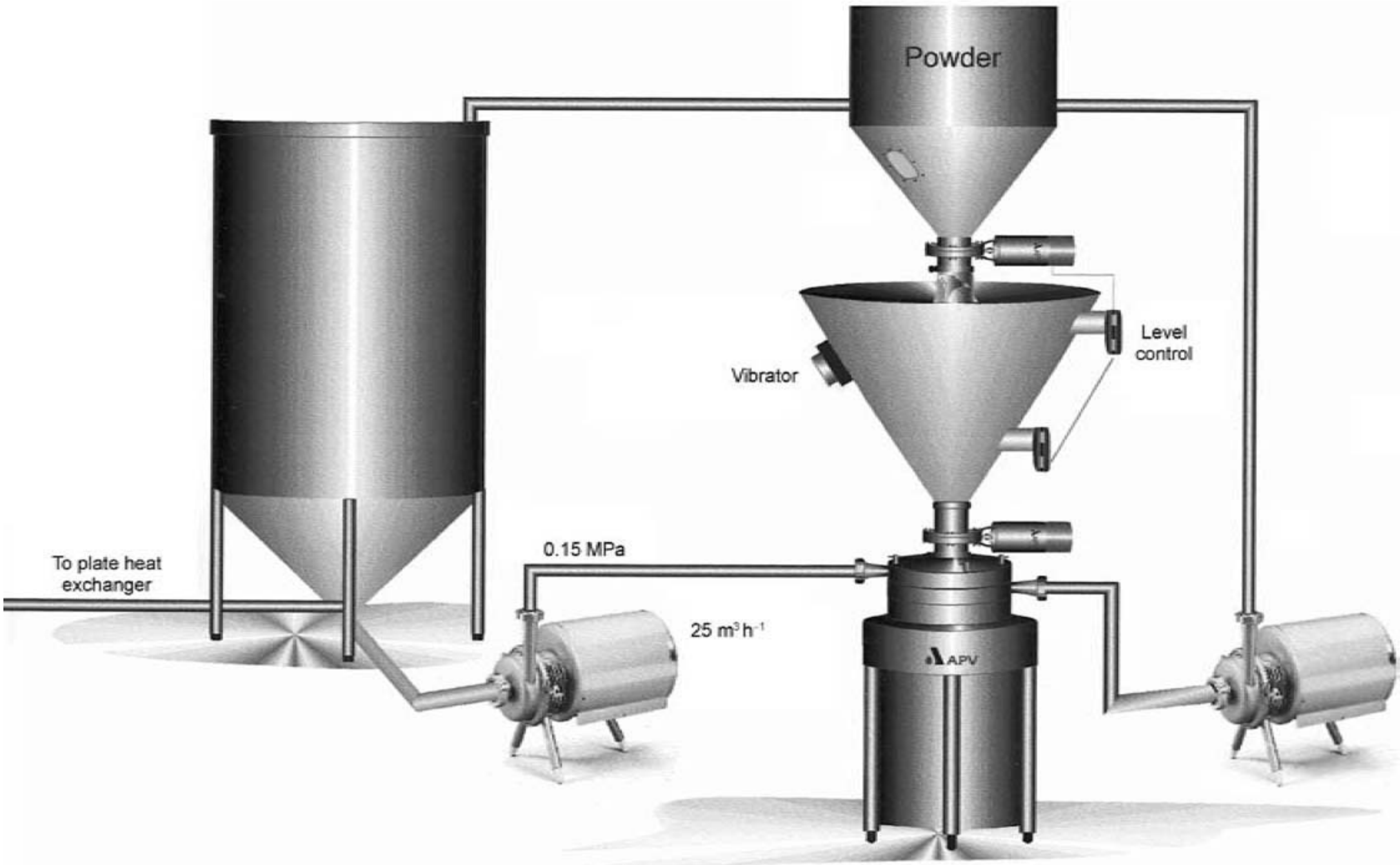

Fig. 3.19 Schematic illustration of TPM-1 powder mixer.
Reproduced by courtesy of APV UK Co Ltd, Crawley, UK.

An alternative method to the funnel/hopper installation is the in-line mixer, and some examples of such units are as follows.

Tri-Blender®

This mixing unit is supplied by the Tri-Clover Inc. of Wisconsin, USA. The principle of this mixing unit is that the venturi jet mixer is replaced with a dual stage blending process (see Fig. 3.20). The system is designed for continuous in-line or batch blending of dry ingredients at a rate of up to 45 kg min^{-1}. The product passes through the initial liquid/dry ingredient blending chamber to a second blending chamber which effectively serves as a discharge pump. This double blend feature improves end-product consistency and provides a smoother and more uniform blend. With the discharge pump function handled within the blender itself, it is possible to achieve significantly higher vacuum rates over a wider range of process conditions. The increased vacuum rates contribute to fast and consistent flow rates throughout an entire production run, and with such a blending system, the additional strainers and a discharge pump are not required. Incidentally, this unit is rather compact and occupies only $50 \times 75\ cm^2$ of floor space (see Fig. 3.20).

Silverson mixers

These types of mixer operate at very high speed and exert an homogenising effect during the recombining of dried ingredients. The models, which could be used for the

Fig. 3.20 Tri-Clovers dual-stage Tri-Blender®.

Reproduced by courtesy of Tri-Clover Inc, Kenosha, USA.

Fig. 3.21 The 'Flashmix' that can be used for in-line mixing of powders. Reproduced by courtesy of Silverson Machines, Chesham, UK.

reconstitution of milk powder, are known as the 'In-Line' and the 'Flashmix'. The latter unit is shown in Fig. 3.21. These machines are designed for continuous operation at high speeds and each has incorporated a high shear rotor/stator processing workhead; the In-Line mixer has one such head and the Flashmix has two. The upper head is normally a general-purpose disintegrating unit, while the lower head is a square hole type with high-shear screen. The operating characteristics of these workheads are briefly described by the manufacturer:

- The liquid is gravity fed or pumped into the hopper and is rapidly drawn down by the two rotor/stator workheads; a vortex is created by the flow of liquid through the Flashmix, and it is into this vortex that the powder is added.
- The liquid/solid mixture is drawn down the vortex into the mixing chamber and has no way of bypassing the workhead(s) assembly, ensuring that all the solids are totally dispersed before leaving the mixing chamber.

Two advantages claimed for the unit are that the workheads can be changed to suit each individual product and that by using the appropriate feeding/metering equipment, the liquid/solid ratio of flow can be precisely controlled. However, a similar unit known as Flashblend can also be used to wet and disperse powders into liquids rapidly but the mode of operation is different.

The use of an In-Line mixer alone has its limitations, because the delivery of milk powder through a funnel into a recirculating circuit inevitably leads to 'arching'.

However, the use of a Flashmix mixer overcomes this difficulty because the liquid and solid ingredients are fed simultaneously into a specially designed hopper before being sucked immediately into the upper rotor/stator. This workhead converts the milk powder/liquid phase into a slurry which is then dispersed as the result of the high-speed shearing effect of the bottom or second workhead. It is obvious that each mixer is designed for a particular purpose and a combination of these two types of mixer in the recombining process brings the advantages of both units, that is, the mixing process involves three workheads rather than one or two, so ensuring complete dissolution of the powder with the minimum incorporation of air. Some degree of homogenisation of the mix can be obtained by using different types of stator head or screen on the high-speed mixer, so that, for example, a disintegrating effect is achieved using large circular holes or slots, a fine screen produces an emulsification/homogenisation effect and a screen with square holes imparts a high shearing effect.

Vacucam™

This type of in-line powder mixer was developed by the SemiBulk Systems Inc. in the United States. An overall illustration is shown in Fig. 3.22. The system has the following features: (a) an air-pallet/ejector mixer section conveys, wets and dispenses the powder into the liquid; since the design generates its own vacuum to draw in the dairy powders, the mixer allows total separation of dry handling from wet processing, and also, by introducing the powder within the liquid stream, powder plugging is avoided, (b) the in-line ejector/mixer conveys and mixes the powder on a 'skidded system' without using mechanical equipment (e.g. conveyors, rotary valves, receivers and in-tank mixers); this system can be fully automated including CIP, and can operate on batch recycle, single pass or continuous modes and (c) the air cone hopper is designed for easy discharge of powders that can cause delivery problems; details of the construction and principles of operation have been given (Anon., 1996b) and the use of low-pressure air or other gases eliminates the bridging effect of the powder in the hopper and facilitates discharge. Incidentally, this system of mixing can be easily used to dissolve sugar into the milk base.

In-tank mixing unit

Efficient mixing of powder in a tank relies entirely on the agitation system provided. The familiar flow pattern which occurs during liquid mixing is illustrated in Fig. 3.23. These patterns are largely influenced by:

- shape and size of the agitator system (paddle, turbine, propeller, scraped surface, anchor, etc.);
- position of the agitator, i.e. top or bottom entering, perpendicular or sloped, and/or centrally mounted or not;
- speed of rotation of the agitator;
- shape of the processing vessel, while more specifically the efficiency of mixing is related to speed of rotation of the agitator, velocity difference between the bulk fluid and the agitator; the creation of a vortex, incorporation of air into the bulk fluid and any shearing effects.

All these factors are relevant to the dispersal of powder into the bulk fluid and hence an equipment manufacturer has various options in terms of design. Recently the practical considerations for reconstituting dairy powders to high solids content in-tank have been reported by Fitzpatrick *et al.* (2001) and Fitzpatrick and Cuthbert (2004).

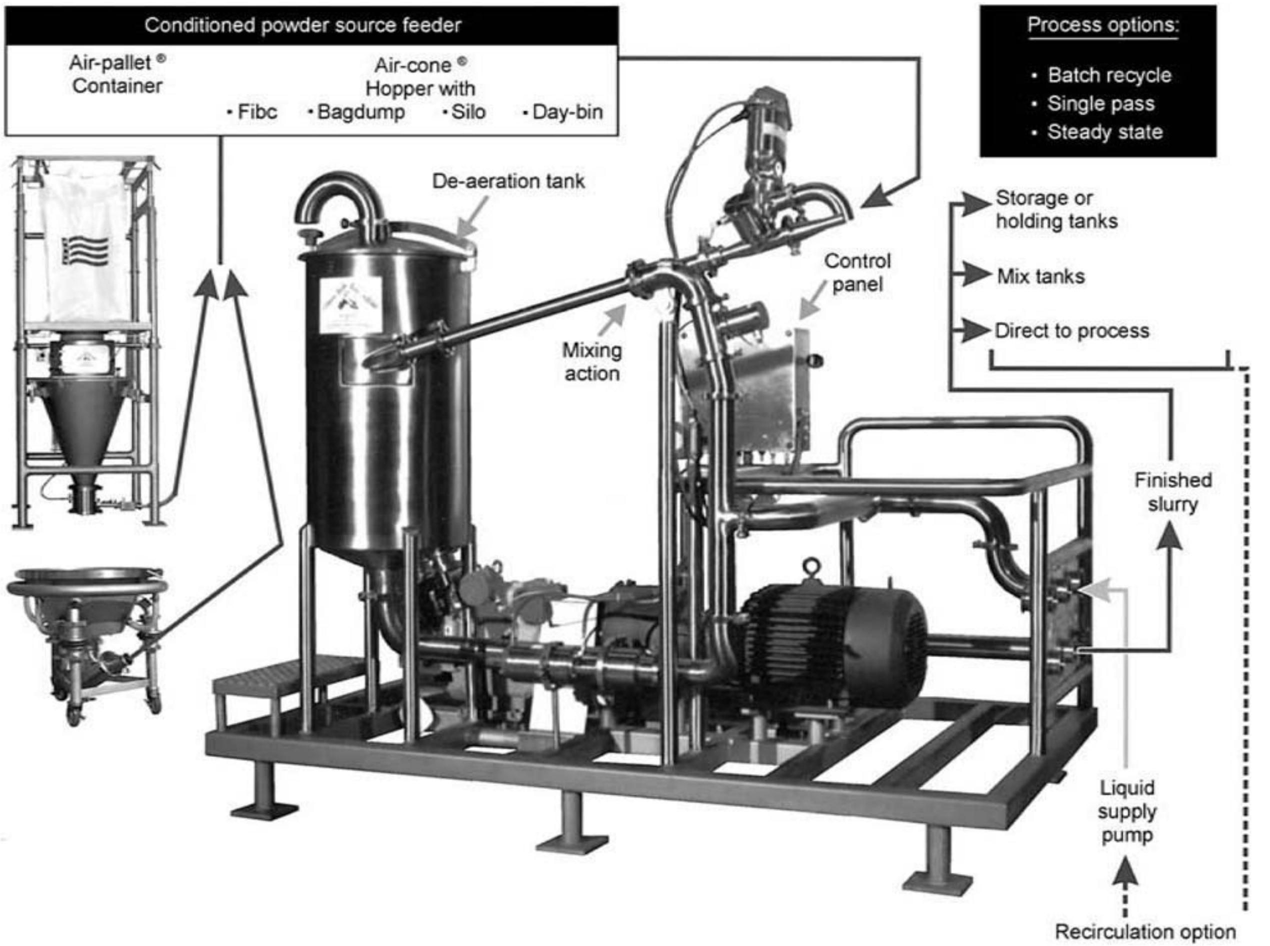

Fig. 3.22 Vacucam™ continuous in-line powder mixing system.
Reproduced by courtesy of Semi-Bulk Systems Inc, Missouri, USA.

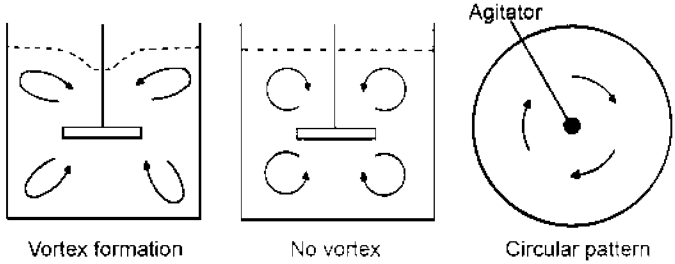

Fig. 3.23 Liquid mixing flow patterns. Note: the paddles are perpendicular, top entering and centrally mounted.

After Tamime and Greig (1979).

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Multipurpose processing tank

This type of tank (i.e. the batch pasteuriser) can be utilised during all stages of yoghurt making (see Fig. 3.6), since the agitation system consists of a high-speed motor which is operated during the preparation and processing of the milk, a slow-speed motor for mixing in the starter and later for cooling the coagulum, and the drive shaft of the slow speed motor can be fitted with a one- or two-propeller agitators and is usually top entering and sloped (see also Anon., 2003).

Simple mixing tank

Different types of high-speed mixer (Silverson and Greaves) could be used in simple tanks that resemble a batch pasteuriser, but do not have a properly mounted agitation system. Thus in yoghurt production, two of these tanks will be installed in parallel for preparation of the milk base, so that while one tank is being emptied, the other tank is normally being filled up; a continuous flow of yoghurt milk to the incubation tanks can be achieved in this way. In practice, a tank is filled with water or milk warmed to around 40–50 °C and the milk powder is emptied from the sacks. Recombination is achieved using a high-shear mixer/homogeniser and the mixers can be mounted permanently in each tank or, alternatively, can be removed from one tank to the other with the aid of a hydraulic lift (see Fig. 3.24).

An older type of high-speed in-tank mixer is the Ystral mixer described by Dalhuisen (1972). The powder mixing procedure is: (a) powder is emptied into the special chute, (b) the high-speed action of the mixing head creates a vacuum at the tip of the powder delivery pipe, thus transferring the powder down the pipe from the chute, and (c) powder/liquid mixing takes place in the absence of air; there is little risk of the powder forming clumps.

Crepaco 'Multiverter'

This is a specially designed tank that provides rapid and complete dispersion of the dried ingredients into the liquid slurry. The tank has a 15° or 35° cone bottom which facilitates easy and rapid unloading and it is fitted with a high-speed motor which drives a special centrifugal agitator. This unique agitator incorporates a 'squirrel cage' design resulting in a dual blending action, combining an overall swirl with a deep-draw vortex that quickly and effectively disperses the milk powder into the aqueous phase with a minimum of foam. Although the tank is specifically designed to emulsify two or more immiscible products, the blending action is especially effective in dispersing any fatty constituents in the yoghurt milk. Furthermore, the tank can also be fitted with a CIP system.

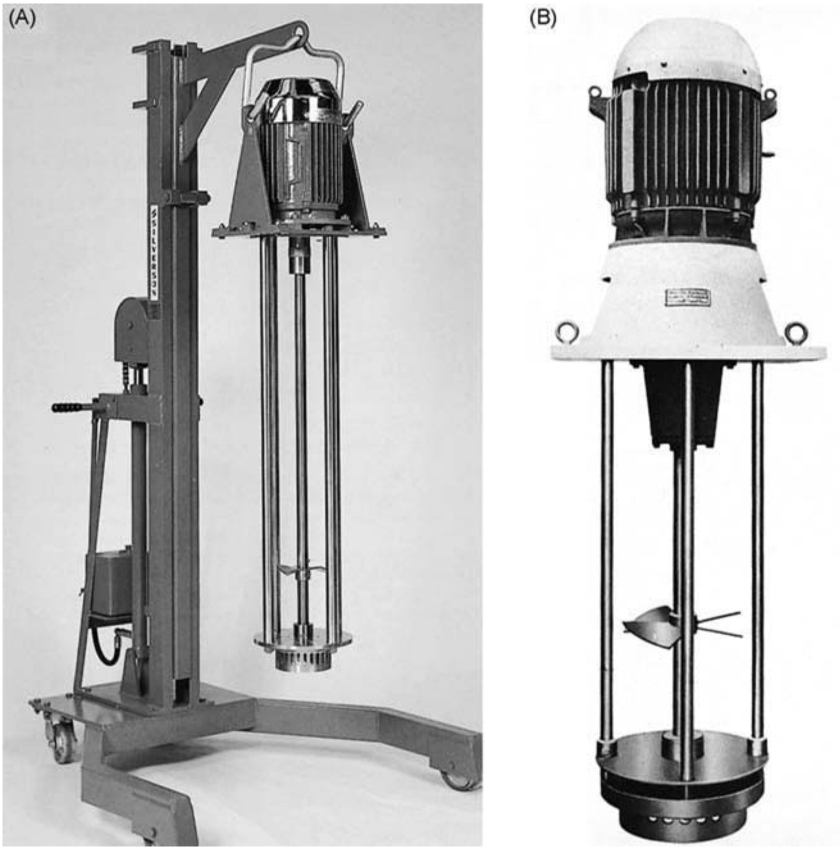

Fig. 3.24 Examples of high-speed mobile mixers (A) Silverson and (B) Greaves.

Reproduced by courtesy of Silverson Machines, Chesham, UK and Joshua Greaves and Sons, Bury, UK.

Crepaco 'Liquiverter'

This high-speed mixer/blender is capable of both dispersing the dry ingredients and incorporating fat into the liquid phase. The impeller/agitator is centrally mounted from the bottom of the square tank and the action of the Liquiverter pulls the added milk powder through the liquid vortex at the centre and forces the mixture up the walls in continuous circulation.

Large-scale recombination plant

Two systems could be used during the large-scale production of a milk base (Anon., 2003; see also Aneja, 1990). In the first system, the fat is dosed into the mixing tank (see Fig. 3.25).

Potable grade water is heated in a PHE to facilitate easy rehydration of the SMP and is metered into one of the storage tanks (see Fig. 3.25 (7)). The circulation pump (5) is started when the tank is half full and water flows through a bypass line from the mixing tank to a high-speed powder blending unit (4). The feed rate of skimmed milk powder (SMP) through the blending system is up to $45\,\text{kg}\,\text{min}^{-1}$. A vacuum is created by an interplay between the circulation pump (5) and the booster pump (6) which causes the blender to draw the ingredients into the eye of the centrifugal impeller. The agitator in the mixing tank is started at the same time as the circulation pump. Water continues to

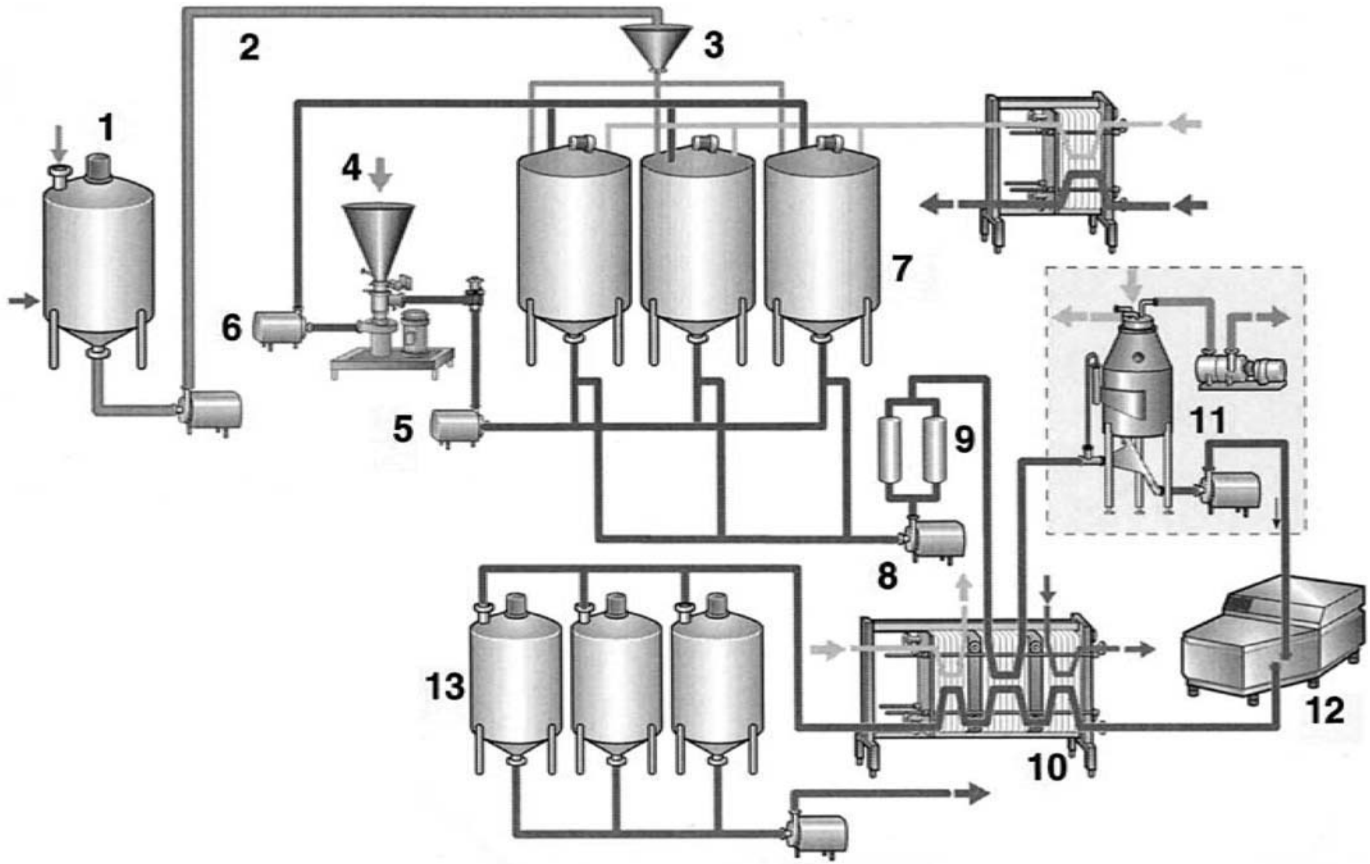

Fig. 3.25 Recombination in a large-scale plant where the fat is added in the mixing tanks.

1, Tank containing melted fat (e.g. cream or anhydrous milk fat (AMF); 2, insulated pipe for delivery of fat; 3, weighing funnel for fat; 4, funnel with high-speed blender (see Fig. 3.20); 5, circulating pump; 6, booster pump; 7, mixing tank; 8, discharge pump; 9, filters; 10, PHE; 11, vacuum de-aerator (optional); 12, homogeniser; 13, storage tanks.

Reproduced by courtesy of Tetra Pak A/B, Lund, Sweden.

flow into the tank while mixing is in progress until the specified quantity has been supplied.

When all the SMP has been added, the agitator and the circulation loop are stopped and the contents of the tank are left until the SMP has dissolved completely. At a water temperature of 35–45 °C this will take about 20 min. At the end of this period the agitator is restarted. In the meantime, the blender is reconnected for the next batch to be recombined. AMF is now added from the fat storage tank (1). The quantity is measured in the weighing funnel (3). The agitator, specially designed for optimum fat dispersion, runs for several minutes and finely disperses the fat in the skimmed milk. The piping for the warm fat fraction is normally insulated to prevent the temperature of the fat from falling below the melting point (see also Kaya, 2000).

When all the ingredients have been mixed and added to one tank, the process is repeated in the next tank. The skimmed milk/fat mixture is drawn from the full mixing tank by pump (8) which forwards the mixture through duplex filters (9). After being preheated in the PHE (10), the product is pumped to the homogeniser (12) where the dispersion of fat globules is completed. During recombination, air might be incorporated into the milk base, and a vacuum de-aerator vessel (11) can be installed in the line before the homogeniser to eliminate this; such a unit can reduce the air content from 1.3–1.8% to 0.1–0.2% which can improve the texture and consistency of the yoghurt (Rage *et al.*, 1987). The product is preheated to 7–8 °C above homogenisation temperature before being flashed in the de-aerator, where the vacuum is adjusted so that the outgoing product has the correct homogenisation temperature, typically 65 °C. The homogenised milk is pasteurised and chilled in the PHE (10) and is then pumped to the storage tanks (13) or direct to packaging. However, for yoghurt production the milk is heated to higher temperature as described in Fig. 3.13.

Alternatively, in-line fat mixing (Fig. 3.26) can be used in which the recombination of the powder is similar to that described in Fig. 3.25 (Anon., 2003). In this system, the process could be described as follows. When a mixing tank has been filled and the contents have been given time for complete hydration of the SMP, the reconstituted skimmed milk is pumped through duplex filters (6) to a balance tank (7) (see Fig. 3.26). This ensures a constant flow rate to the process. A centrifugal pump (8) feeds the skimmed milk through a preheating section of the PHE (9). Although the addition of fat can suppress foaming in the skimmed milk, in this instance, a de-aerator vessel (10) is required. The milk base is preheated and homogenised in the manner described in Fig. 3.25, but then the milk flows through an in-line injector (13) where liquid fat from the fat-melting tank (11) is continuously metered into the flow by a positive displacement proportioning pump (12). Blending is completed in an in-line mixer (14) downstream of the injector. Immediately after mixing, the recombined milk continues to a high-capacity homogeniser (15) and then returns to the PHE (9) for further processing as described in Fig. 3.13.

When dealing with the recombination of milk powder, two conditions in the reconstituted milk have to be monitored. First, not all the particles of milk may dissolve during the recombining process, perhaps through the use of poor quality powders, inefficient mixing equipment and/or the presence of scorched particles. Any undissolved particles must be removed using in-line stainless steel mesh, or a stainless steel mesh and nylon filter called the duplex, or centrifugal, clarifiers. Clarifiers are excellent for the removal of any fine or undissolved particles and any extraneous matter but, for convenience, filters are more commonly used. Normally two interchangeable filters are installed in a milk reconstitution line, especially in large dairies, so that in the case of clogging, the flow of milk can be easily diverted while one of the filters is being cleaned.

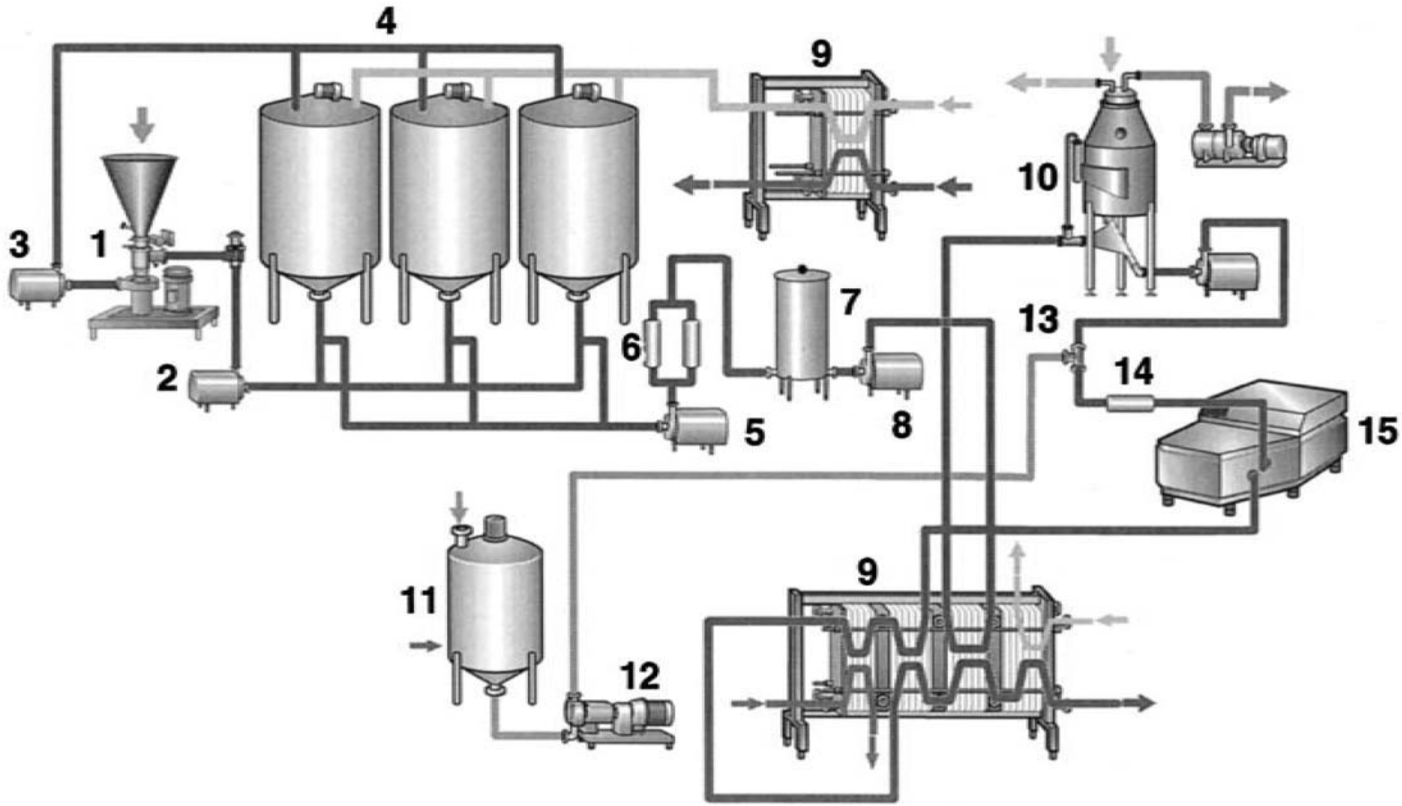

Fig. 3.26 Large-scale recombination plant with in-line fat mixing.

1, Funnel with high-speed mixer (see Fig. 3.20); 2, pump for circulation; 3, booster pump; 4, mixing tanks; 5, discharge pump; 6, filters; 7, balance tank; 8, feed pump; 9, PHE; 10, vacuum de-aerator; 11, tank containing melted fat (e.g. cream or AMF); 12, positive displacement pump; 13, fat injector; 14, in-line mixer; 15, homogeniser.

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The removal of such particles is essential, since their presence in the milk can damage the orifices in a homogeniser and/or increase soiling in heat exchangers. Second, reconstituted powders require up to 15 min to achieve complete hydration, otherwise sedimentation becomes evident. The hydration effect may not be important during the manufacture of yoghurt, since the time elapsing between recombination and the end of heat treatment of the milk can be as long as 15 min.

Evaporation of milk

Concentration of standardised milk base can be achieved by use of an evaporator, in which the average amount of water removed is 10–25 g 100 g^{-1} and the total solids is increased by 1.5–3.0 g 100 g^{-1}, corresponding to the recommended fortification with milk powder (Anon., 2003). In order to remove the desired amount of water and avoid damage to the milk constituents at high temperatures, the process of evaporation is normally carried out under vacuum.

Single-effect evaporators can be used directly in a yoghurt processing line. The milk base is pumped from the balance tank to the condenser where it is preheated and then enters the plate section of the evaporator for further heating. After reaching the preset temperature, the milk flows to the separator section and water vapour is removed from the milk; the cycle is repeated until the desired concentration of total solids in the milk base has been reached. Heat recovery during the evaporation process is very efficient and is achieved using a thermocompressor, that is, factory steam is mixed with the vapour produced from the evaporator.

Another type of single-effect evaporator that could be used to concentrate the milk base is supplied by Tetra Pak A/B. The sequence of operations is as follows. The standardised milk base is preheated to 70 °C in the regeneration section of the PHE using the condensate from the evaporator (see Fig. 3.13). Subsequently the milk is heated to 85–90 °C in the heating section of the PHE and the preheated milk enters the vacuum chamber where the inlet is shaped as an expansion tube to prevent burning of the milk. The milk is recirculated four to five times until the desired degree of concentration is achieved. The recirculation cycle is controlled by the capacity of the vacuum chamber, evacuation pump and the float controller; during each recycle, about 3–4 g 100 g^{-1} of water is removed. The capacity of such evaporators is up to 8000 l h^{-1}, but for larger plants, different types of evaporators are used with capacities up to 30 000 l h^{-1}.

In general these evaporators offer the advantages of minimum requirement for space, efficient heat recovery and immediacy of use. Furthermore, yoghurt made from milk concentrated in this way exhibits an excellent organoleptic quality.

Membrane concentration of milk

An alternative method of fortification of the milk base is by concentration of the milk (whole and/or skim) by membrane filtration (i.e. UF and RO). The basic differences between the UF and the RO systems are first that the operational pressures are much higher in the case of RO, and second that the RO membrane is less permeable than the UF membrane; the pore size for RO is <40 nm and for UF is >200 nm (see Fig. 3.27).

The milk constituents that pass through a membrane are referred to as the permeate, and the material that does not pass through the membrane (i.e. concentrated fraction) is known as the retentate. The different components present in milk can be divided into three main groups based on the molecular weight, that is, large molecules (proteins and fats), medium (lactose and salts) and small (water). The RO membrane allows only the small molecules (water) to pass through the membrane and the retentate consists of a